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(21) International Application Number: PCT/US98/02641 (22) International Filing Date: 13 February 1998 (13.02.98) (30) Priority Data: 08/799,365 14 February 1997 (14.02.97) US (71) Applicant: UNIVERSITY OF MARYLAND BALTIMORE COUNTY [US/US]; 5410 Wilkens Avenue, Baltimore, MD 21228 (US). (72) Inventors: GOLOVCHENKO, Ekaterina, A.; 5138 Darting Bird Lane, Columbia, MD 21044 (US). PILIPETSKII, Alexei, N.; 5138 Darting Bird Lane, Columbia, MD 21044 (US). MENYUK, Curtis, R.; 13308 Locksley Lane, Silver Spring, MD 20904 (US). (74) Agent: NATH, Gary, M.; Nath & Associates, Suite 750, 1835 K Street, N.W., Washington, DC 20006 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
(54) Title: REDUCTION OF COLLISION INDUCED TIMING JITTER BY PERIODIC DISPERSION MANAGEMENT IN SOLITON WDM TRANSMISSION <div data-bbox="487 1155 1136 1701" data-label="Diagram"> </div> (57) Abstract <p>Collisions between solitons in different frequency channels are one of the major sources of errors in transmission systems that utilize wavelength division multiplexing (WDM). Moreover, because standard transmission lines have lumped amplification, the four-wave mixing fields from soliton collisions grow uncontrollably, adding amplitude and timing jitter to the jitter due to ideal soliton collisions. These problems are addressed by using specific dispersion map (100) to implement dispersion management, by which it is possible to significantly reduce the collision-induced timing jitter and to improve system performance even in comparison with that provided by an ideal, exponentially decreasing dispersion fiber (40).</p>		

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REDUCTION OF COLLISION INDUCED TIMING JITTER BY PERIODIC
DISPERSION MANAGEMENT IN SOLITON WDM TRANSMISSION

FIELD OF THE INVENTION

5 The present invention generally relates to a method
and apparatus for reducing errors in transmission systems
caused by collisions between solitons in different frequency
channels, and particularly in transmission systems that
utilize wavelength division multiplexing (WDM).

BACKGROUND OF THE INVENTION

10 The above invention was supported by NSF Grant ECS
- 9113382 and the government has certain rights to this
invention.

15 Collisions between solitons in different frequency
channels are one of the major sources of errors in
transmission systems that utilize wavelength division
multiplexing (WDM). Moreover, because standard transmission
lines have lumped amplification, the four-wave mixing fields
from soliton collisions grow uncontrollably, adding amplitude
and timing jitter to the jitter due to ideal soliton
20 collisions. According to the present invention, these
problems are addressed by using proper dispersion management,
by which it is possible to significantly reduce the
collision-induced timing jitter and to improve system
performance even in comparison with that provided by an ideal,
25 exponentially decreasing dispersion fiber.

Further, the present invention may significantly improve
the performance of soliton communication systems
with both time

division multiplexing (TDM) and wavelength division multiplexing (WDM).

The present technology of WDM soliton systems uses either uniform dispersion fiber or dispersion decreasing fiber.

Various devices and methods are known pertaining to the transmission of solitons for use in telecommunications. Additionally, wave division multiplexing (WDM) is known in the field of telecommunications. Examples of such devices are discussed further hereunder.

U.S. Patent No. 5,557,441 issued to Mollenauer discloses a soliton transmission system having plural sliding-frequency guiding filter groups to control timing jitter. The optical filters are arranged in groups whose average center frequency differs from the other groups along the length of the transmission line. The groups are arranged so as to have frequency increasing, frequency decreasing, and combinations of both, to reduce noise while permitting transmission of solitons.

U.S. Patent No. 5,471,333 issued to Taga et al. discloses solitons, wherein wavelength dispersion is controlled by a fiber having first sections which have an average value of wavelength dispersion which is larger than the dispersion value meeting with the soliton condition, and second sections with an average value of the wavelength dispersion smaller than the dispersion value meeting with the soliton condition. The average value of the wavelength dispersion of the entire length of the optical fiber transmission line assumes a positive value.

U.S. Patent No. 5,579,428 issued to Evans et al. was cited for teaching a single mode optical waveguide fiber using soliton signal pulses with a dispersion flattened waveguide. This reference fails to teach periodic dispersion management, nor does it address the problem of reduction of collision induced timing jitter, among other differences.

U.S. Patent No. 5,523,874 issued to Epworth discloses an optical soliton pulse transmission system that replaces passive optical filters with active optical filters. A loop tunes the center frequency of the filter to provide a specific offset from the center frequency of the solitons.

U.S. Patent No. 5,504,829 issued to Evans et al. discloses soliton transmission in fiber having a refractive index that monotonically decreases along the fiber.

U.S. Patent No. 5,550,671 issued to Simpson et al. discloses Wavelength Division Multiplexed (WDM) technology. Similarly, U.S. Patent No. 5,546,210 issued to Chraplyvy et al. discloses 4-wave mixing products with channel carriers and WDM technology.

U.S. Patent No. 5,530,585 issued to Reid et al. discloses a dispersion shifted fiber for use in soliton optical transmission. U.S. Patent No. 5,469,525 issued to Luther-Davies et al. discloses dark spatial soliton technology.

However, the foregoing references do not address the problem of reduction of collision induced timing jitter, and the use of periodic dispersion management to solve this problem. Further

the foregoing references do not address the problem of improving soliton WDM transmission using periodic dispersion management.

SUMMARY OF THE INVENTION

5 The present invention is directed to an optical fiber and an apparatus useful in improving soliton WDM transmission using periodic dispersion management. Further, the present invention addresses the problem of reduction of collision induced timing jitter, and employs periodic
10 dispersion management to solve this problem.

 As discussed hereinabove, collisions between solitons in different frequency channels are one of the major sources of errors in transmission systems that utilize wavelength division multiplexing (WDM). Moreover, because standard
15 transmission lines have lumped amplification, the four-wave mixing fields from soliton collisions grow uncontrollably, adding amplitude and timing jitter to the jitter due to ideal soliton collisions. The present invention, by using proper dispersion management, significantly reduces the
20 collision-induced timing jitter and improves system performance even in comparison with that provided by an ideal, exponentially decreasing dispersion fiber.

 The present invention is based on the use of alternating-sign dispersion management. A dispersion map is provided to
25 allow significant reduction of collision-induced timing jitter in WDM systems. Such dispersion-managed fiber systems are technologically easier to construct than is a system based on

dispersion-decreasing fibers. The dispersion map according to the present invention does not use any special fibers, and can be constructed from standard and dispersion-shifted fibers.

Furthermore, a particular feature of the present invention is that the dispersion map enables solitons to propagate through almost 90% of the path in normal dispersion fiber which in general does not support soliton propagation.

An object of the present invention is accordingly to improve the quality of information transmission, while at the same time improving the information capacity of the transmission fibers used.

Another object of the present invention is to improve both single and multiple channel soliton transmission.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a uniform dispersion fiber.

Fig. 1B illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a dispersion-decreasing fiber.

Fig. 1C illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a dispersion-managed fiber according to the present invention.

Fig. 1D is a chart of symbols used in Figs. 1A-1C versus channel number.

Fig. 2 is a schematic diagram of a dispersion map according to the present invention.

5 Fig. 3A illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a uniform dispersion fiber.

10 Fig. 3B illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a dispersion-decreasing fiber.

15 Fig. 3C illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a dispersion-managed fiber according to the present invention.

Fig. 4A illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a uniform dispersion fiber.

20 Fig. 4B illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a dispersion-decreasing fiber.

25 Fig. 4C illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a dispersion-managed fiber according to the present invention.

Fig. 5A illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a uniform dispersion fiber.

5 Fig. 5B illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a dispersion-decreasing fiber.

10 Fig. 5C illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a dispersion-managed fiber according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

15 Figs. 1A-1C compare the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for various types of fiber, as follows. Fig. 1A illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a uniform
20 dispersion fiber. Fig. 1B illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel unfiltered WDM system, for a dispersion-decreasing fiber. Fig. 1C illustrates the standard deviation of jitter in soliton arrival times versus
25 propagation distance for an eight-channel unfiltered WDM system, for a dispersion-managed fiber according

to the present invention. The symbols used in Figs. 1A-1C correspond to channel numbers according to the chart in Fig. 1D. These figures are discussed further hereunder, with reference also to Fig. 2, in which Fig. 2 is a schematic diagram of a dispersion map according to the present invention.

In Fig. 2, a dispersion map 100 is shown for a filter 30 and a normal dispersion fiber 40. A amplifier 10 is connected to the filter 30, and the length of the normal dispersion fiber 40 is approximately 35 km, and is followed by an approximately 5 km length of anomalous dispersion fiber 50. The anomalous dispersion fiber 50 is connected to an amplifier 20.

The present invention shown in Fig. 2 includes an improved optical fiber and optical fiber arrangement having improved periodic dispersion management, and an apparatus useful in improving soliton WDM transmission using periodic dispersion management. The present invention as shown reduces collision induced timing jitter by use of periodic dispersion management.

Collisions between solitons in different frequency channels are one of the major sources of errors in transmission systems that utilize wavelength division multiplexing (WDM). Moreover, because standard transmission lines have lumped amplification, the four-wave mixing fields from soliton collisions grow uncontrollably, adding amplitude and timing jitter to the jitter due to ideal soliton collisions. The present invention employs dispersion management to significantly reduce the collision-induced timing jitter and thereby improve system performance,

even in comparison with that provided by an ideal,
exponentially decreasing dispersion fiber.

The present invention is based on the use of alternating-
sign dispersion management. A dispersion map as shown in Fig.
2 and described further hereunder, is provided to allow
significant reduction of collision-induced timing jitter in
WDM systems. The dispersion map according to the present
invention does not use any special fibers, and can be
constructed from standard and dispersion-shifted fibers.

Also, the dispersion map of the present invention enables
solitons to propagate through almost 90% of the path in normal
dispersion fiber which in general does not support soliton
propagation. Further, both single and multiple channel
soliton transmission can be used in the present invention.

The present invention uses dispersion management to
reduce collision-induced timing jitter in soliton WDM
transmission, and as a result the performance of dispersion
managed fibers provides better performance than either
dispersion-decreasing fibers and fibers with uniform
dispersion. This is applicable both for filtered and
unfiltered systems. This is discussed further hereunder.

A major source of errors in soliton wavelength-division-
multiplexed (WDM) transmission is collision-induced timing
jitter. Because standard transmission lines have lumped
amplification, the four-wave mixing fields from soliton
collisions grow uncontrollably even when the spacing between

amplifiers is much smaller than the soliton collision length, adding amplitude and timing jitter to the jitter due to ideal soliton collisions. It has been proposed in the technical literature [P.V. Mamyshev and L.F. Mollenauer in Opt. Lett. 21, 397 (1996)] to use dispersion-decreasing fiber to reduce the four-wave mixing fields. However, by the present invention, dispersion management is shown to be a viable alternative to dispersion-decreasing fiber.

Remarkably, as discussed further hereunder, computational results show that solitons in dispersion-managed fibers can actually suffer less impairment than solitons in ideal dispersion-decreasing fibers with the same average dispersion when the channel spacing is less than about 10 pulse spectral widths.

Dispersion-managed fibers, i.e., fibers with dispersion maps that alternate in sign, have long been used in non-return-to zero transmission. There has been recent interest in also using dispersion management in soliton transmission to suppress Gordon-Haus timing jitter by decreasing the path-averaged value of dispersion [M. Suzuki, I. Morita, S. Yamamoto, N. Edagawa, H. Taga, and S. Akiba, Electron. Lett. 23, 2027 (1995)] and to suppress filtered soliton instabilities in WDM [S. Wabnitz, Opt. Lett. 21, 638 (1996)].

Computer simulations of up to eight WDM soliton channels were performed. Each such soliton channel was filled with pseudo-random 32 bit sequences of 20 ps solitons spaced in time

by 5 FWHM. The path-averaged dispersion was $D = 0.5$ ps/nm-km, and the amplifier spacing was 40 km. For the system with no in-line filtering, the amplifiers exactly compensated for the fiber loss. For the filtered transmission system, Fabry-Perot
5 etalons were placed at the same location as amplifiers, and the filter transmission frequency was shifted with a rate close to the critical sliding rate [P.V. Mamyshev and L.F. Mollenauer, Opt. Lett. 21, 397 (1996)]. The amplifier gain
10 for the filtered system was slightly increased to compensate for additional losses introduced into the system by the filters. In view of the calculating of the timing jitter from soliton collisions, the Gordon-Haus timing jitter was not included. To reduce the initial partial collision the soliton
15 sequences in neighboring channels were shifted by half a time slot. It was found that a single channel in a fiber with uniform dispersion has transmission characteristics that are indistinguishable from a dispersion decreasing fiber with an ideal exponential taper. These calculations showed that when
20 the WDM channels are spaced by 12 pulse spectral widths, the dispersion-decreasing fiber has the smallest jitter, but the performance of the dispersion-managed fiber is much better than the uniform dispersion fiber. This is shown in the following discussion with respect to Figs. 1-5.

Fig. 1 shows the calculated standard deviation of the
25 tuning jitter σ versus transmission distance for an eight-channel WDM system with channels spaced by 6 pulse spectral widths. The

specific fibers under study included a fiber with uniform dispersion, a dispersion decreasing fiber with an ideal exponential taper, and a periodically dispersion managed fiber with the sign of the dispersion changing between the amplifiers.

A dispersion map according to the present invention is shown in Fig. 2. According to this dispersion map, a 35 km fiber is provided with normal dispersion $D_1 = -2$ ps/nm-km which is followed by a 5 km fiber with anomalous dispersion $D_2 = 18$ ps/nm-km to provide the average value of anomalous dispersion $D = 0.5$ PS nm-km. In this case, the total length of the dispersion map equals the amplifier spacing. According to the present invention as shown in Fig. 2, the solitons in dispersion-managed fibers suffer less impairment than solitons in ideal dispersion-decreasing fibers with the same average dispersion when the channel spacing is less than about 10 pulse spectral widths. Accordingly, the dispersion-managed fiber demonstrates the best performance.

For the unfiltered system, the timing jitter in the side channels for the dispersion-decreasing fiber is low, but drastic errors occur in the central channels. It is the central channels that are the most strongly affected by the collisions. By the present invention as shown in Figs. 1 and 2, it is possible by managing the dispersion to actually have less timing jitter than is the case for ideal soliton collisions.

The pulse train of the central channel for the unfiltered system is shown in Figs. 3A-3C. As shown in Figs. 3A-3C, the

normalized pulse intensity of pulse trains are shown in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km. In these figures, the pulse intensity is normalized to the intensity of an average soliton in a transmission line with lumped amplification.

In Fig. 3A, the normalized intensity is shown with respect to time (ps) for a uniform dispersion fiber. In Fig. 3B, the normalized intensity is shown with respect to time (ps) for a dispersion decreasing fiber. In Fig. 3C, the normalized intensity is shown with respect to time (ps) for a dispersion managed fiber.

As seen in Figs. 3A-3C, the amplitude jitter in the dispersion-managed fiber (Fig. 3C) is larger than in the dispersion-decreasing fiber (Fig. 3B).

Fig. 3A illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a uniform dispersion fiber. Fig. 3B illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a dispersion-decreasing fiber, and Fig. 3C illustrates the normalized pulse intensity of pulse trains in a demultiplexed 4th channel of an eight-channel unfiltered WDM system at 5,000 km, for a dispersion-managed fiber according to the present invention.

Fig. 4A illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a

uniform dispersion fiber. Fig. 4B illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a dispersion-decreasing fiber. Fig. 4C illustrates the spectral intensity for the spectrum of the eight-channel unfiltered WDM system at 5,000 km, for a dispersion-managed fiber according to the present invention.

Further, as seen in Figs. 4A-4C, the power of a four-wave mixing field in the dispersion-managed fiber (Fig. 4C) is larger than in the dispersion-decreasing fiber (Fig. 4B).

Nevertheless, the dispersion-managed solitons are less impaired overall.

The introduction of in-line filters decreases the collision-induced timing jitter by a factor in a range of two to three.

Fig. 5A illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a uniform dispersion fiber.

Fig. 5B illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a dispersion-decreasing fiber.

Fig. 5C illustrates the standard deviation of jitter in soliton arrival times versus propagation distance for an eight-channel WDM system with in-line filtering, for a dispersion-managed fiber according to the present invention.

Figs. 5A-5C show the calculated standard deviation of the timing jitter σ versus the transmission distance for an eight-

channel WDM system with channels spaced by 6 pulse spectral widths for the case of the filtered system. As can be seen from these figures, the dispersion managed system (Fig. 5C) demonstrates the best performance.

5 The above result is particularly significant because it is currently far easier to construct a dispersion-managed system than it is to construct a system with an ideal exponential taper. Moreover, by the present invention, it should be possible to operate with lower average dispersion,
10 thus lowering the amount of timing jitter.

 The invention being thus described, it will be evident that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention and all such modification are intended to be
15 included within the scope of the following claims.

What is claimed is:

1. An apparatus for reducing errors in transmission systems caused by collisions between solitons in different frequency channels, comprising:

5 a telecommunications arrangement for soliton transmission formed by a dispersion map which employs dispersion management; and

said dispersion map including a dispersion-managed fiber system.

10 2. An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes a normal dispersion fiber connected to an anomalous dispersion fiber.

15 3. An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes a filter connected to a normal dispersion fiber.

20 4. An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber, and an anomalous dispersion fiber connected to said normal dispersion fiber.

5. An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber having a length of approximately 35 km, and an anomalous dispersion fiber having a length of approximately 5 km and connected to said normal dispersion fiber.

6. An apparatus for reducing errors in transmission systems caused by collisions between solitons in different frequency channels for use in transmission systems that utilize wavelength division multiplexing, comprising:

a telecommunications arrangement for soliton transmission formed by a dispersion map which employs dispersion management; and

said dispersion map including a dispersion-managed fiber system.

7. An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes a normal dispersion fiber connected to an anomalous dispersion fiber.

8. An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes a filter connected to a normal dispersion fiber.

9. An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber, and an anomalous dispersion fiber connected to said normal dispersion fiber.

10. An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber having a length of approximately 35 km, and an anomalous dispersion fiber having a length of approximately 5 km and connected to said normal dispersion fiber.

11. An apparatus for reducing errors in transmission systems caused by collisions between solitons in different frequency channels for use in transmission systems that utilize wavelength division multiplexing, comprising:

a telecommunications arrangement for soliton transmission formed by a dispersion map which employs dispersion management; and

said dispersion map including a dispersion-managed fiber system, to significantly reduce collision-induced timing jitter and to improve system performance in comparison with that provided by an ideal, exponentially decreasing dispersion fiber.

12. An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes a normal dispersion fiber connected to an anomalous dispersion fiber.

5 13. An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes a filter connected to a normal dispersion fiber.

10 14. An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber, and an anomalous dispersion fiber connected to said normal dispersion fiber.

15 15. An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes an amplifier, a filter connected to said amplifier, a normal dispersion fiber having a length of approximately 35 km, and an anomalous dispersion fiber having a length of approximately 5 km and connected to said normal dispersion fiber.

20 16. An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system is adapted for use in time division multiplexing.

17. An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes alternating-sign dispersion management.

5 18. An apparatus as claimed in claim 6, wherein said dispersion-managed fiber system includes alternating-sign dispersion management.

19. An apparatus as claimed in claim 11, wherein said dispersion-managed fiber system includes alternating-sign dispersion management.

10 20. An apparatus as claimed in claim 1, wherein said dispersion-managed fiber system includes both standard and dispersion-shifted fibers.

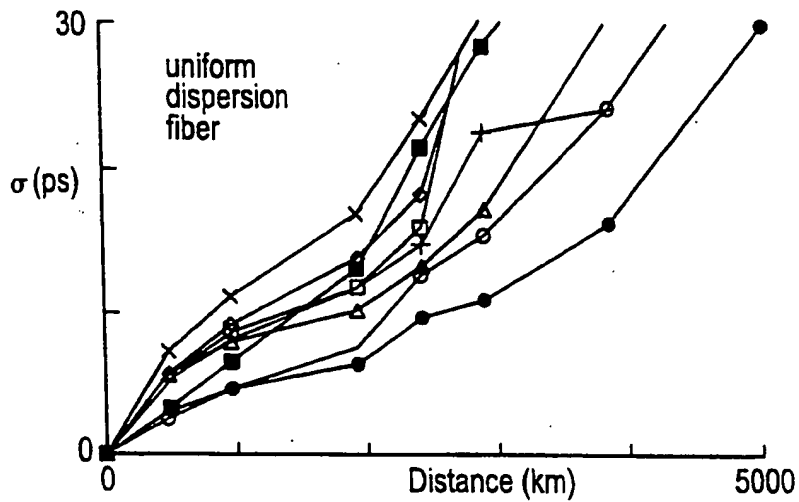
FIG. 1A^{1/5}

FIG. 1B

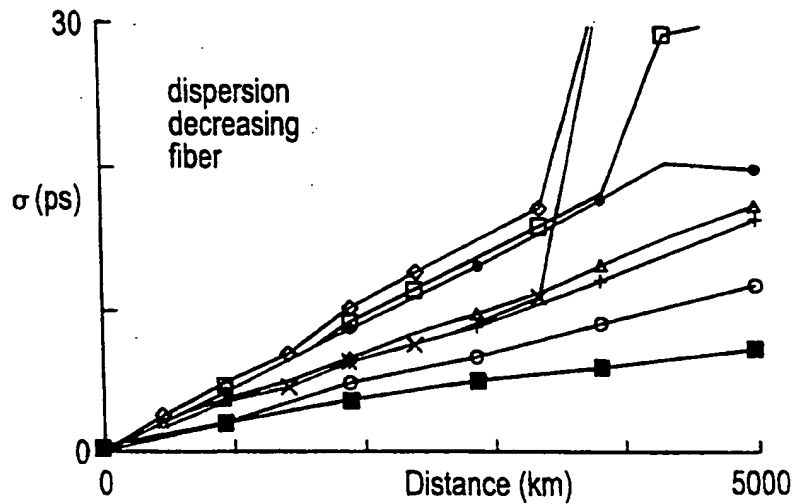


FIG. 1C

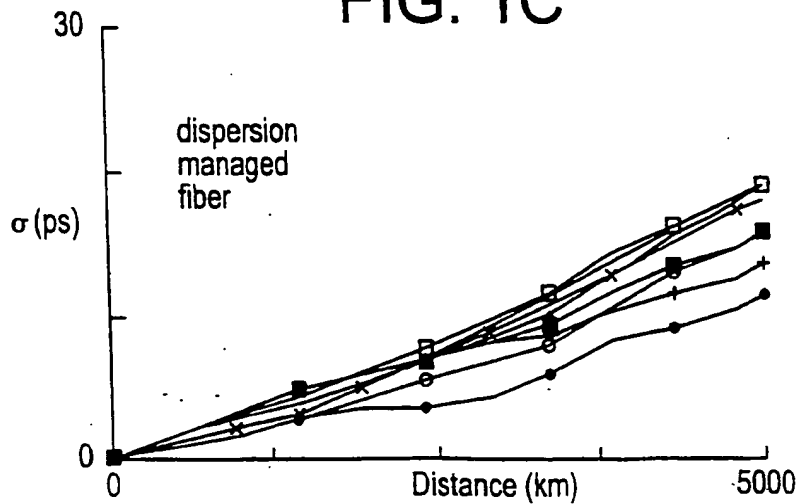


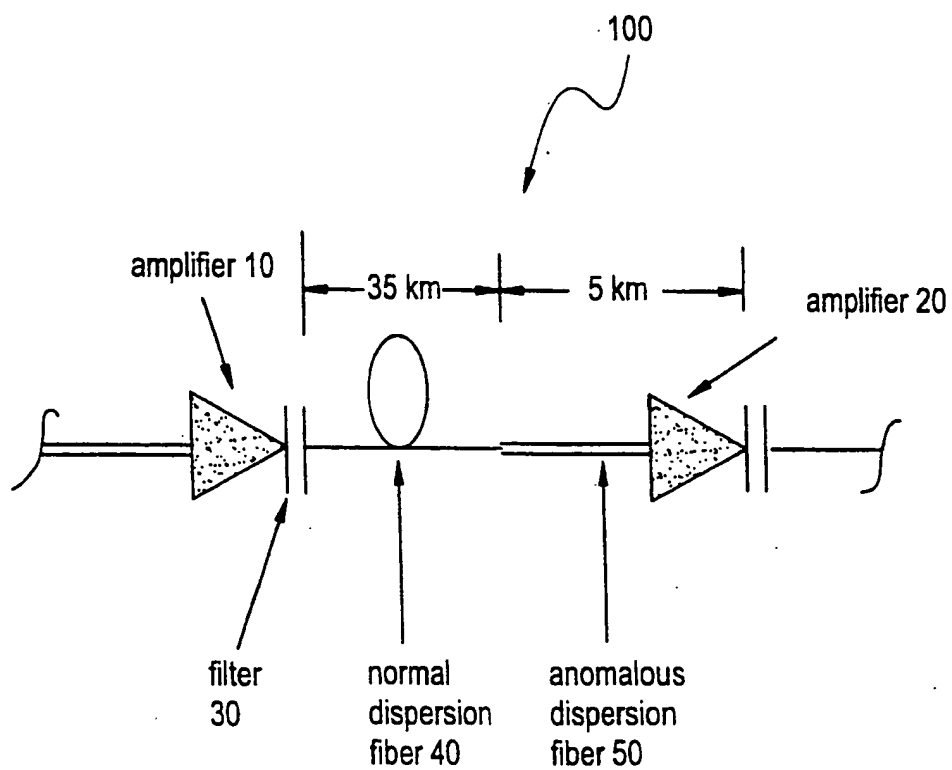
FIG. 1D

channel number

- 1
- 2
- ◇ 3
- × 4
- + 5
- △ 6
- 7
- 8

2 / 5

FIG. 2



3 / 5

FIG. 3A

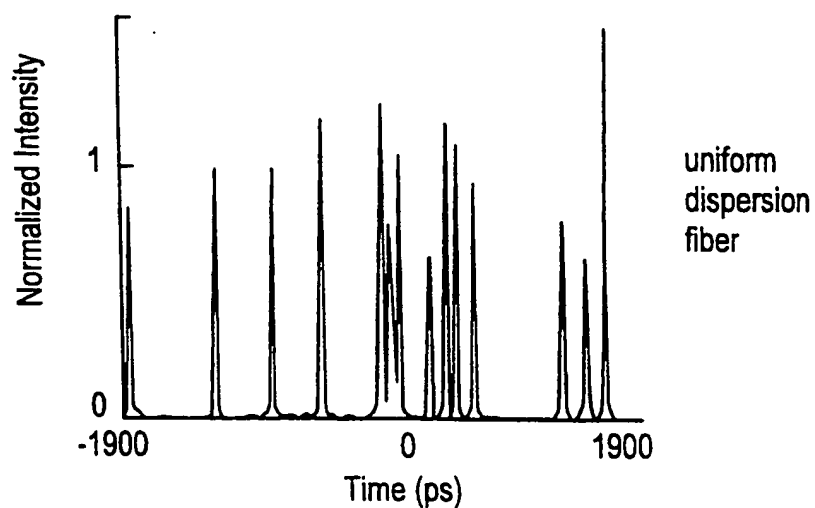


FIG. 3B

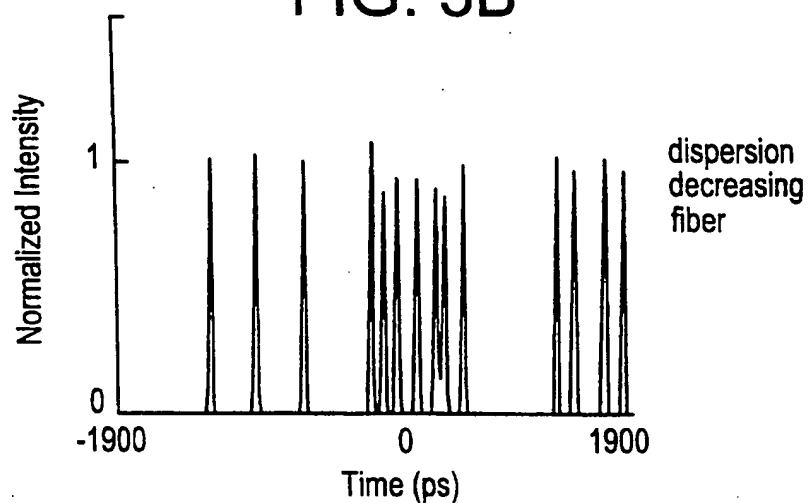


FIG. 3C

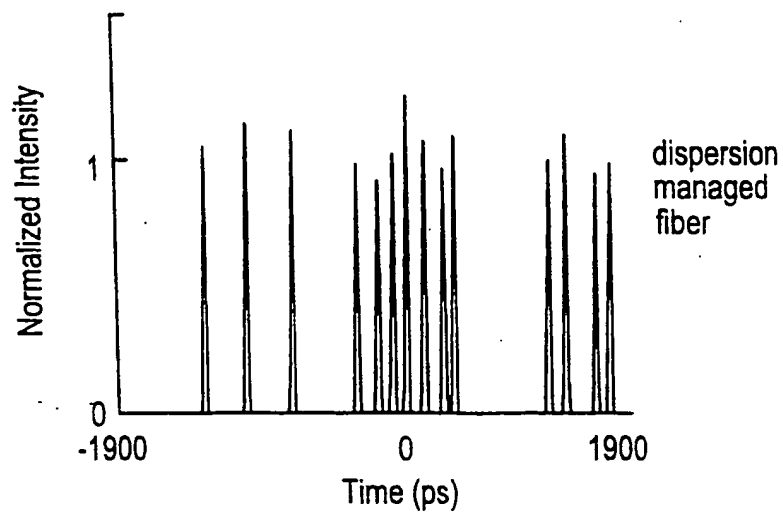


FIG. 4A

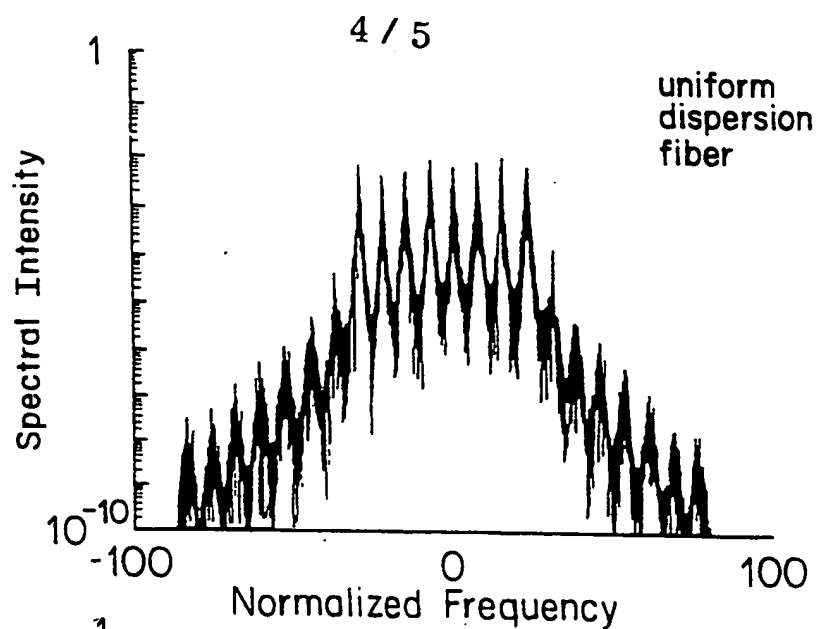


FIG. 4B

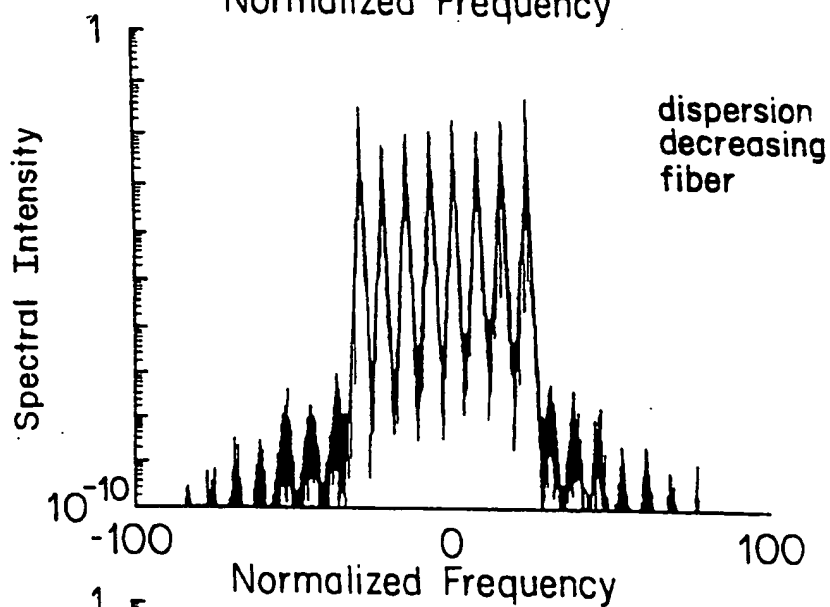
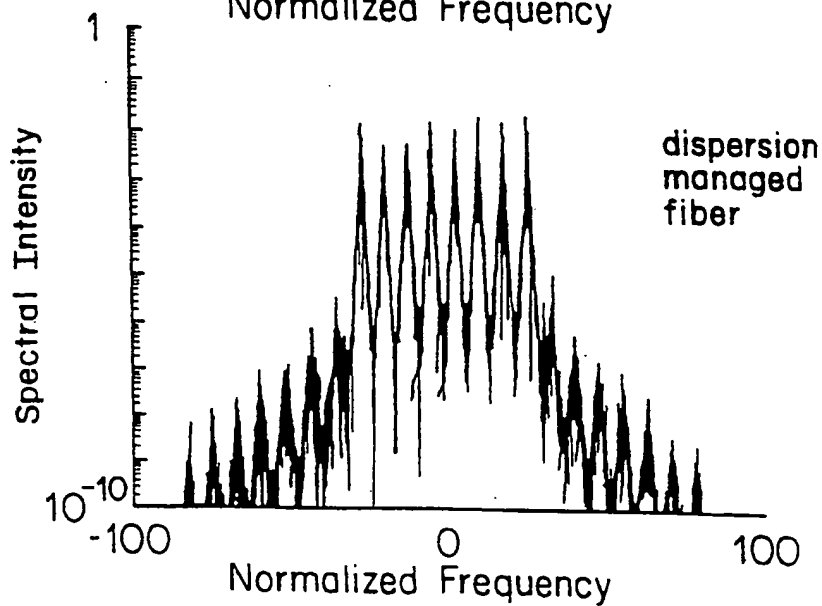


FIG. 4C



5 / 5

FIG. 5A

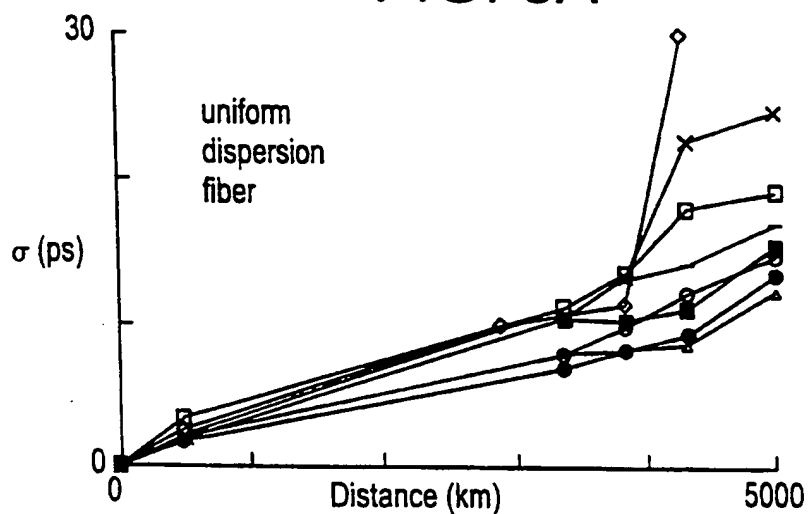
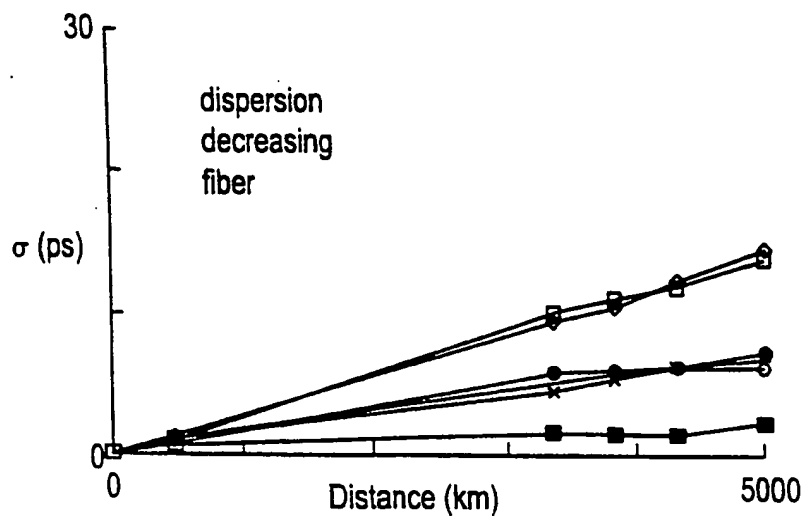
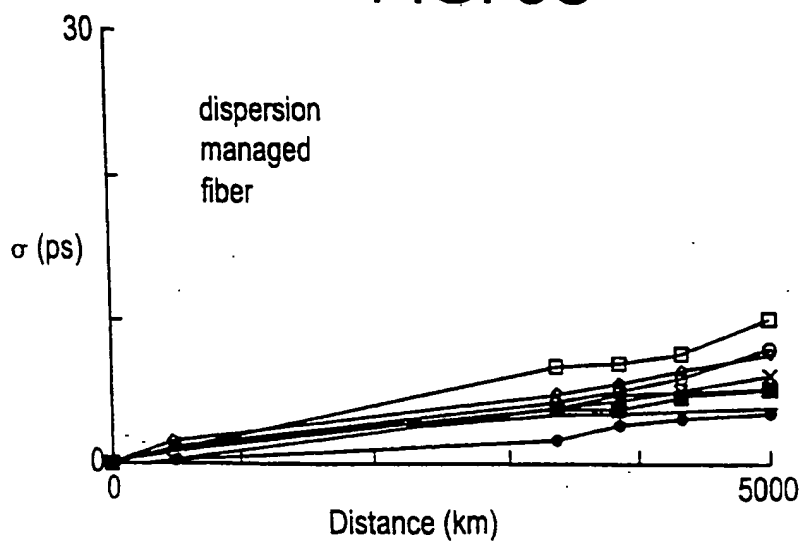


FIG. 5B

channel
number

- 1
- 2
- ◇— 3
- ×— 4
- +— 5
- △— 6
- 7
- 8

FIG. 5C



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/02641

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H04B 10/00

US CL : 359/161,160,173,188,179

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/161,160,173,188,179

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	DEVANEY, J.F.L. ET AL., Modelling WDM Soliton Transmission in Dispersion-Managed Systems, IEE, 06 February 1997, pages 1-4. London, UK.	1-2,6-7,11-12,20 ----- 3-5,8-10,13 -19
X	HASEGAWA, A. ET AL., Reduction of Collision-Induced Time Jitters in Dispersion-Managed Soliton Transmission Systems, Optics Letters, 01 January 1996. Vol. 21 , No. 1. Pages 39-41.	1,6, and 11
Y	MATSUZONO, T. ET AL., Transmission Characteristic Improvement of Two-Channel Wavelength Division Multiplexed Solitons by Controlling Initial Time Offset, LEO '96 Conference Proceeding 9th Annual Meeting IEEE Lasers and Electro-Optics Society, 18-19 November 1996. Boston, MA.	3-5,8-10,13-19

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
B earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

15 APRIL 1998

Date of mailing of the international search report

19 JUN 1998

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